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Full Length Research Paper

An empirical mathematical model for smoke attributed mortality

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This paper presents a simple empirical mathematical model which predicts the increase in mortality caused by cigarette smoking. The model considers the introduction of new brands of cigarette in the market and (or) the introduction of new smokers in a given population. The model is used to predict the smoke attributed mortality (SAM) for a period of 20 years, say, using empirical data of Nigeria population. A means through which the government and the policy makers would use to control the SAM is suggested.

Key words: Mortality, empirical mathematical model, smokers, government.

INTRODUCTION

The rate at which smoke attributed mortality (SAM) increases and the effort needed to reduce tobacco caused death are of great interest to policy makers in setting goals for tobacco control program.

Health problems rarely occur in isolation or for obvious reasons, instead of guessing at what might be wrong and hoping that suggestion will work, we would prefer to know what is really going on inside our body based on the many signs it gives us.

It is extremely important to obtain an accurate diagnosis before trying to find a cure. Many diseases and conditions share common symptoms; if you treat yourself for the wrong illness or specific symptoms of a complex disease you may delay the legitimate treatment of a serious underlying problem. In other words, the greatest danger in self treatment is self diagnosis. If you do not know what you really have, you cannot treat it well. Cigarette (tobacco) smoke is a dangerous practice with more than 500 known poisons (see Table 1). Every time a smoker lights up, he (she) is being injured to some degree by inhaling these poisons. Lung cancer is the leading causes of cancer death in men. Women who smoke have an overall increasing death rate and are dying at an earlier age than male smokers (HRO/World Bank, 1993).

Although most smokers are aware of the harmful effect of smoking, this may not be enough to overcome the reasons why they are smoking. A careful review of the reasons why people continue to smoke may help them come to the conclusion that it is time to quit.

CIGARETTE - THE HEALTH BURDEN

There are no longer any debates surrounding the health consequences caused by tobacco use. The use of tobacco products has been linked to more than thirty diseases, including bronchitis, emphysema, cirrhosis of the liver, smoker's face, decreased birth weight, peripheral vascular disease, peptic ulcer, hypertension, Buerger's disease, heart diseases, strokes, chronic respiratory disease, pulmonary tuberculosis and cancers of the lungs, lip and tongue cancer, gum cancer, bladder and pancrease cancer, mouth and oesophagus cancer, pharynx and larynx cancer (see Table 2).

In the year 2000, an estimated 4.9 million deaths were caused by tobacco use, without further action it is predicted that by the year 2020 the mortality burden attributed to tobacco will near double and approximately 70% of these deaths will occur in developed countries.

The pressure on tobacco is not limited to cigarette smoking, use of other tobacco product such as bid smoking and tobacco quid chewing has been shown to play a significant role in the development of fatal disease (Creaser and Purchase, 1991).

In addition to heart disease, cigarette smoking, with an

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increase consumption of polyunsaturated fatty acid is the single major cause of cancer death in the United States (Fiber and Vahter, 1983). Cigarette smokers have total overall cancer death rate twice that of non smokers. The greater the number of cigarette smoked, the greater the risk. Smoking alone increase lungs cancer risk by as much as forty times.

MATHEMATICAL MODEL

A huge effort had being (and is being) invested into developing mathematical models by academics and practitioners alike which describe and predict the rate of mortality caused by different kinds of diseases.

Goldstein et al. (2005) developed a mathematical model to calculate the age specific risk of acquiring hepatitis b virus (HBV) infection, acute hepatitis b (illness and death) and progress to chronic HBV infection.

Shank et al. (1977) derived a nine compartment model which was described by first-order kinetics. Their linear mammillary compartmental model was used to approximate the observed laboratory values in their investigation. This model was also shown to be valuable for predicting the retention of Cadmum (one of the metallic content of cigarette) in species without adjusting any of the rate constants.

In this paper, we introduced simple models which predict the current death rate caused by cigarette consumption in terms of time t (measured in years). The model is used to predict the smoked attributed mortality (SAM) for a period of years (20 years) using empirical data of Nigeria population. Unlike Shark et al. (1976) model, we adjusted the rate constants due to so many variables involved in our model.

Model formulation

Let α denote the standard death rate which is expected be about some percentage of the entire population, and y the death population that increases by units of packs or brand of cigarette smoked. Since the number is large for a given α, we will approximate the real situation by regarding y as a continuous function of the continuous variable t. That is

y = y (t).

We now formulate $\frac{dy}{dx}$ as the rate of death caused by cigarette intake which will increase the standard death rate as $-\alpha y$. On the other hand, new brand of cigarette will be added as well as new smokers, thereby increasing the rate of death caused by cigarette intake. We denote this by β, so that the net rate of death caused by cigarette with time t is obtained by

$$\frac{dy}{dx} = \beta t - \alpha y \tag{1}$$

This is a linear equation of the standard form

$$\frac{dy}{dx} + \alpha y = \beta t, \tag{2}$$

with integrating factor $e^{-\alpha t}$. It is easy to see that

$$y(t) = ce^{-\alpha t} + e^{-\alpha t}\int e^{\alpha t}\beta t\, dt = ce^{-\alpha t} + \frac{\beta t^2}{2}, \tag{3}$$

is the situation of equation (2). C is the assumed initial population size at time t.

The regression equation of (2) gives

$$\log y(t) = \log c - \alpha t + 2\log t + \log\left(\frac{\beta}{2}\right) = 2\log t - \alpha t + \log\left(\frac{c\beta}{2}\right). \tag{4}$$

For t = 0, we have

$\log y(0) = \log\left(\frac{C\beta}{2}\right), \beta = 0,1,2,...,$ which is the intersection along the $\log y$ axis.

On the other hand, let the rate of decrease in a given population be proportional to the increase in death due to smoke attributed disease (SAD). We express this mathematically as;

$$\frac{dI}{dt} = \beta SI - \gamma I, \tag{5}$$

where β and γ are constants of proportionality, with γ known as the rate of introduction of new brand of cigarette and β the introduction of new smoker into the population, these govern how fast the population decreases due to SAM. Equation (5) is a differential equation with two unknown sizes of the population S and I (both are functions of x), with I the population of non-smokers while S is the population of smokers. Thus,

$$N_t = S_t + I_t, \tag{6}$$

with $N_0 = S_0 + I_0$ where N denotes the total population. Using Equation (6), we now write (5) as

$$\frac{dI}{dt} = \beta(N - I)I - \gamma I = KI - \beta I^2, \tag{7a}$$

Table 1. Metal content of cigarette in difference countries (Spiff et al., 1999; Ebisike et al., 2004; Elinder et al., 1983a; 1983b; Jung et al., 1998).

Country	Metal content (ug/g)				
	Pb	Cd	Zn	Ni	Cu
Korea	1.35	1.02	38.5	0.23	7.73
UK	0.74	0.90	31.9	0.12	13.0
India		0.19	42.6		
Mexico		0.34	52.5		
Yugoslavia		2.2			
Argentina		0.55	33.1		
Finland		1.32	41.6		
Japan		1.98	50.56		
People's Republic of China		0.7	41.67		
Srilanka		0.39 (0.33 - 0.46)	39.4 (36.4 - 47.2)		
Sweden		1.52 (1.14 - 1.85)	38.7 (34.4 - 43.5)		
New Zealand		0.23-0.56			
Nigeria	0.48 - 0.55	0.013 - 0.016 0.097 - 0.119 (ug/cigar)			
US		0.93 - 1.90 (ug/cigar)			

Table 2a. Trace of metal content in urine (Ebisike et al., 2004).

Metals	Smokers	Non smokers
Pb	0.32	0.11
Zn	0.31	0.10
Cu	0.69	0
Cd	0.18	0.03
Ni	0.5	---

Table 2b. Trace of metal content in saliva of smokers (Ebisike et al., 2004).

Metals	Smokers	Non smokers
Pb	0.13	---
Zn	0.12	---
Cu	0.34	0.053
Cd	0.053	---
Ni	0.14	---

where

$$K = N - \gamma \tag{7b}$$

Equation (7) is a Bernoulli equation with K and β being constants. We write (7) for $V = I^{-1}$ as

$$\frac{dV}{dt} + KV = \beta\,, \tag{8}$$

which is now a linear equation in V. For $N = \gamma$ in Equation (7b), (8) becomes

$$\frac{dV}{dt} = \beta \tag{9}$$

with solution

$$I_t = \left(\beta t + {}^{1}/_{I_0}\right)^{-1}. \tag{10}$$

For $N \neq \gamma$, the solution of Equation (8) can be easily

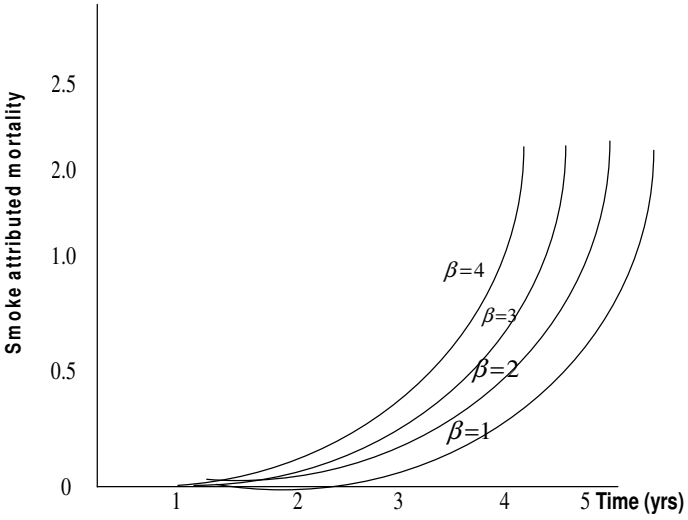

Figure 1. The death rate caused by cigarette intake with different β's and t assuming C = 1500 using Equation (3) and the standard death rate α = 3% of C.

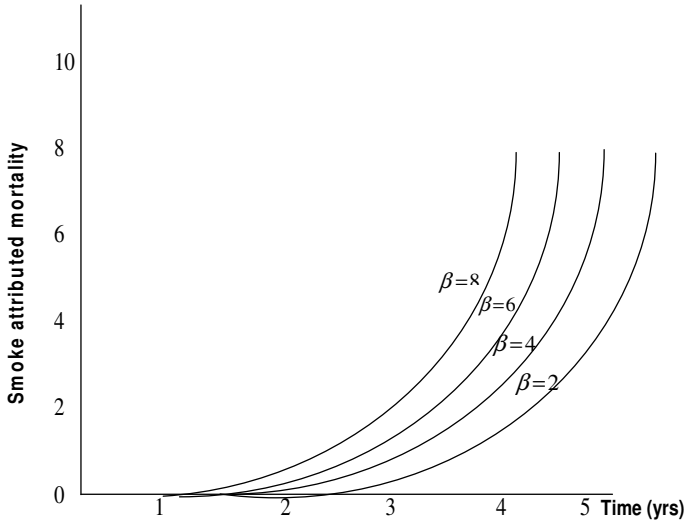

Figure 2. Smoke attributed mortality with t = 2 and different β's, C = 1500 and α = 3 percent of C.

obtained as,

$$I_0 = \frac{KI_0e^{Kt}}{K+\beta I_0(e^{Kt}-1)} = \frac{I_0e^{Kt}}{1+K^{-1}\beta I_0(e^{Kt}-1)} \quad . \qquad (11)$$

The increase in β which denotes the number of new brand of cigarette introduced to a given population as well as new smokes introduced into smoking increases the death rate of a given population as observed in Figures 1, 2, 3 and 4.

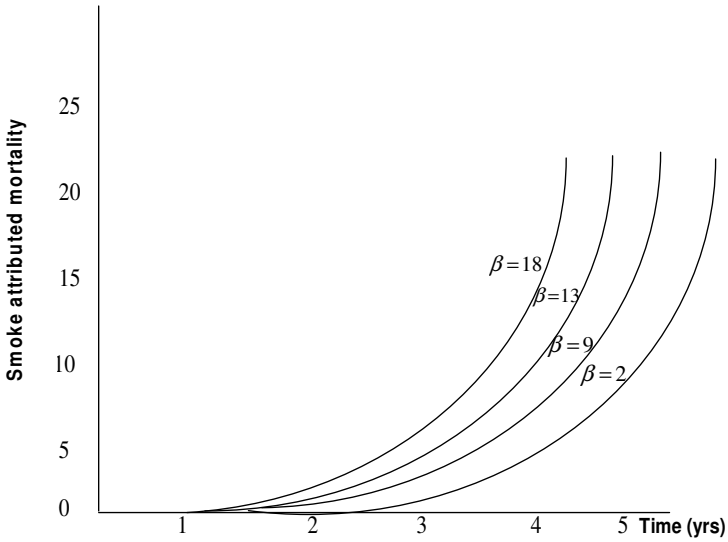

Figure 3. Smoke distributed mortality with t =3 and different β's.

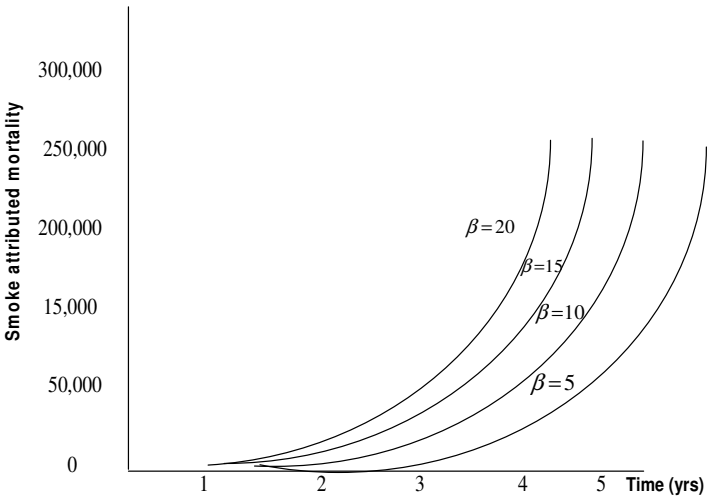

Figure 4. Predicted deaths caused by cigarette intake between 2001 and 2020 with different β's and time t.

Evaluation and prediction with model

The model equations in its simplicity is very useful to predict the smoke attributed mortality (SAM) for years. It is also relevant to know what would happen to the future population with different time intervals say, yearly and as death rate caused by cigarette intake β also increases.

The question here is what would happen to a given country (Nigeria, say) with known population size if the death rate caused by cigarette β continues to increase.

Let us assume the population of Nigeria in the year 2001 to be 50,000 people, let the death rate per year be

Table 3. The SAM predicted with our model by equation.

Years (T)	Population growth rate 23%	Current population predicted	Number of death per year 19%	Smoke attributed fraction of deaths 11%
2001	---	50,000	---	---
2002	11,500	61,500	9,500	5,500
2003	14,145	75,645	11,685	6,765
2004	17,398	93,043	14,373	8,321
2005	21,400	114,443	17,68	10,235
2006	26,322	140,765	21,744	12,589
2007	32,376	173,141	26,745	15,484
2008	39,822	212,963	32,897	19,045
2009	48,981	261,944	40,769	23,426
2010	60,247	322,191	49,463	28,814
2011	74,104	396,295	61,216	35,441
2012	91,148	487,445	75,296	43,592
2013	112,112	599,555	92,614	53,619
2014	137,898	737,453	113,915	65,951
2015	169,614	907,067	140,116	81,110
2016	208,609	1,115,692	172,343	99,77
2017	256,609	1,372,301	211,981	122,726
2018	315,629	1,687,930	260,737	150,953
2019	388,244	2,076,154	320,707	185,672
2020	477,515	2,553,669	394,469	228,377

19% of the entire population with population growth rate per year being 23% of the population and the smoke attributed fraction of death per year to be 11% of the entire population. Our model predicts the smoke attributed mortality (SAM) in the next 20 years in Table 3. It is discovered from Table 3 that more than half of the total death per year is due to cigarette intake. If the current smokers will quit and new members id not join smoking, more than 228,3377 lives would be saved from SAM in the year 2020.

DISCUSSION AND CONCLUSION

Diseases have had a devastating effect on human populations. The lives of several millions of people all over the world have been changed by diseases. In some of the more severe epidemics, families and villages have been destroyed and many of those who survived, their health and lifestyles have changed as a result (Korve, 2009). Many of these severe diseases are due to tobacco consumption.

Tobacco consumption through cigarette is a problem assuming an alarming proportion in Nigeria. Statistics revealed that more than 10,000 million sticks of cigarette were consumed in Nigeria in 1995 with an average of 300 cigarettes per person per year (Ebisike et al., 2004; Shafey et al., 2003).

The observation that it is becoming increasingly difficult to quit smoking has necessitated research at developing a vaccine which intercepts the nicotine in the blood stream and prevents it from reaching the brain to induce the so-called 'reward' (Nnorom et al., 2005).

Discover from Equation (11) that as

$$t \to \infty, I_t \to \frac{K}{\beta} = N - \frac{\nu}{\beta},$$

this implies that as time t increases, the population of non-smokers reduces due to the introduction of new brands of cigarettes as well as new smokers. Efforts should be made therefore by the government at discouraging consumption of cigarette. One suggested way of the government doing this is by increasing the prices of tobacco products. Increasing the prices of tobacco products is arguably the most effective method of cutting the prevalence of tobacco use and reducing consumption of tobacco products. Individuals who do not use tobacco may refrain from starting, and thus avoid addition thereby decreasing the SAM. High prices can also induce current users to consume less tobacco or persuade them to quit, also can discourage ex-users from resuming the habit.

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